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Prediction of Gas Lubricated Foil Journal Bearing Performance

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April 2003

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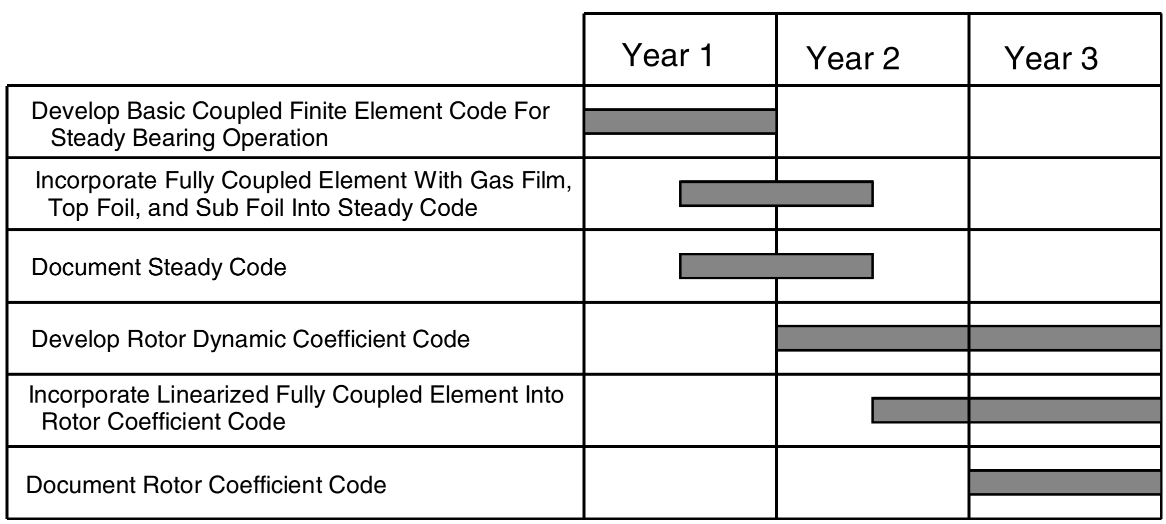
I. Project Objectives

As proposed, the project objectives are: (i) to theoretically predict the steady operating conditions of a foil journal bearing, and (ii) to theoretically predict rotor dynamic coefficients of foil bearings for rotor system stability analysis. The schedule of general tasks is:



II. Project Status

The project is currently in the middle of its eighth month. First year efforts are focused on the generation of a finite element code for steady bearing performance predictions and the academic development of a graduate student. Progress is currently on or ahead of schedule.

II.1 Finite Element Code

A code that predicts various aspects of steady bearing performance such as: film thickness, pressure, load, drag, and mass fluxes has been developed and demonstrated. The code (FOIL2) utilizes a fully-coupled finite element formulation with a Newton-Raphson solver. A special element that simultaneously includes the effects of the foil structure and of the gas film has been incorporated into the code. The top foil is modeled as a thin flat shell element with bending and membrane effects. The gas film is modeled with a compressible Reynolds equation. The sub-foil structure is currently modeled as a simple elastic foundation.

Data for a typical journal bearing is given in Table 1. Contours of the pressure, the film thickness, and the radial deflection of the foil are shown in Figures 1, 2, and 3 for a symmetric half of the bearing. The mass flow vectors are shown in Figure 4. In these figures, the gas enters at the bottom of the figure and moves upward. The line of symmetry is on the left edge. The top, bottom, and right edges are at ambient pressure.

The contours in Figures 1 and 2 show that the pressure increases as the film thickness decreases initially and then the pressure decreases below ambient as the clearance increases. The film thickness in Figure 2 and the radial deflection in Figure 3 are virtually constant in the axial direction. This is because of membrane and bending effects in the foil. Other calculations where the membrane and bending effects were eliminated exhibited large changes with respect to the axial coordinate demonstrating the importance of these effects. Mass flux vectors for the gas flow are shown in figure 4. As would be expected, gas flows axially out of the lower half of the bearing and into the upper half of the bearing.

When the operational documentation is completed and incremental eccentricity has been implemented, a version of the FOIL2 code will be given to NASA personnel. We anticipate that this will occur in the mid-November time frame.

II.2 Graduate Student

Mr. Matthew Smith has been hired as the graduate student working on the project. Mr. Smith completed his B. S. in Mechanical Engineering from The Pennsylvania State University in May 2002. During this Fall 2002 semester he is focusing on coursework in Solid Mechanics, Controls, Machine Dynamics, and Partial Differential Equations. In the Spring 2003 semester, he will take courses in fluid film lubrication and conductive heat transfer. Mr. Smith will start direct project work in the December/January timeframe by first learning the structure and operation of the FOIL2 code. He will then learn how to incorporate new elements and physical effects into the code. Beyond this, Mr. Smith will address transient foil/sub-foil interactions for the prediction of rotor dynamic coefficients. Issues include sub-foil locking and Coulomb friction damping. We are planning to have Mr. Smith visit the NASA Glenn Research Center in January.

III. Near Term Project Plans

The following tasks are planned for the immediate future:

- Exercise and check the FOIL2 code. This is an ongoing process.
- Submit paper on the general finite element approach for foil journal bearings to *Tribology Transactions*.
- Document the operation of the FOIL2 code and its underlying algorithms.
- Install incremental eccentricity capability for large eccentricity and loads in the FOIL2 code. This should enhance convergence at large eccentricities.
- Enable "foil detachment" between the top foil and the foil sub-structure when the sub-structure is in tension.
- Develop and implement a complex sub-foil model in the FOIL2 code. This model will incorporate circumferential extension or "swelling" of the sub-foil structure when it is compressed in the radial direction.
- Address high Knudsen number (slip) effects in the gas flow. Slip effects reduce load capacity at very small film thicknesses and may be significant in highly loaded bearings.
- Investigate sub-foil locking and Coulomb friction effects for steady and transient operation.
- Start the second phase of the project involving the prediction of rotor dynamic coefficients.

Table 1 – Journal Bearing Parameters

Journal Diameter: 2 inches
Bearing Length: 2 inches
Nominal Clearance: 0.001 in
Top Foil
  Modulus of Elasticity: 30 X 10^6 psi
  Poisson's Ratio: 0.3
  Membrane Stiffness: 99,000 lbs/in.
  Bending Stiffness: 0.0742 lbs-in.
Elastic Foundation
  Stiffness: 49,000 lbs/in^3
Rotor
  Speed: 10,000 RPM
  Surface Speed: 1047 in/sec.
  Eccentricity: 0.0009 in
  Eccentricity Angle: 3.1415 radians
Gas
  Viscosity: 2.6 X 10^{-9} Reyns

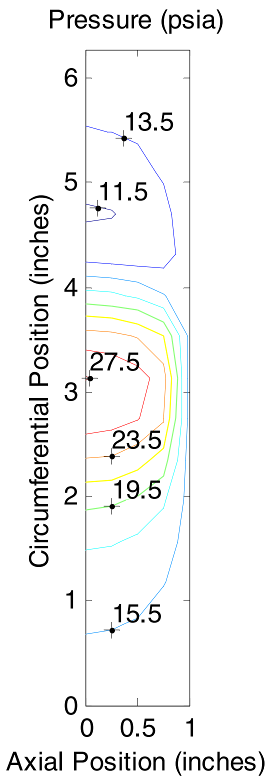


Figure 1.—Pressure (psia).

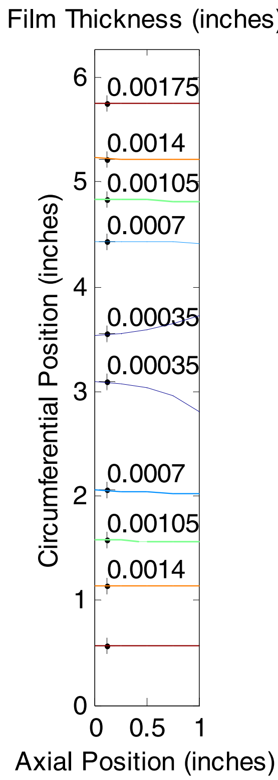


Figure 2.—Film thickness (inches).

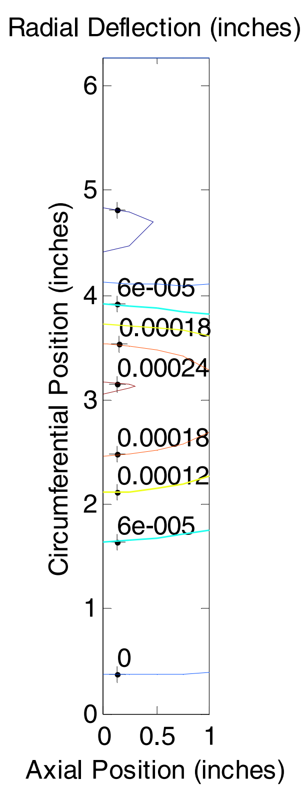


Figure 3.—Radial deflection (inches).

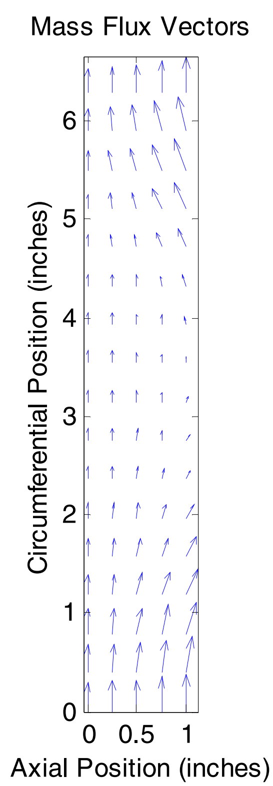


Figure 4.—Mass flux vectors.

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13. ABSTRACT ***(Maximum 200 words)***

This report summarizes the progress in the first eight months of the project. The objectives of this research project are to theoretically predict the steady operating conditions and the rotor dynamic coefficients of gas foil journal bearings. The project is currently on or ahead of schedule with the development of a finite element code that predicts steady bearing performance characteristics such as film thickness, pressure, load, and drag. Graphical results for a typical bearing are presented in the report. Project plans for the next year are discussed.

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